Single-filter installations can be grouped into three broad categories: in-wall (filter mounted in or to a wall penetration of a room, glovebox, hot cell, or other contained space); in-duct (filter installed "in line" between two sections of duct, with or without transitions); and duct-entrance (filter installed at the opening of the duct leading from a room, glovebox, hot cell, or other contained space). In-wall installations are generally employed to clean the air entering a contained space, to prevent backflow of contamination in the event the contained space becomes pressurized, or both. The filter may be installed bare (sides of case exposed) or in a partial enclosure. As in other installations, a prefilter is recommended upstream of the HEPA filter. Duct-entrance filters are strongly recommended to maintain the cleanliness of contaminated exhaust and air cleanup ducts. These should be mounted in or close to the entrance of the duct and, like the in-wall type installation, may be installed either bare, as shown in **FIGURE 6.5**, or in a partial enclosure.

In-duct open-face filters should be installed in totally enclosing housings or side-access housings, as shown in **FIGURE 6.6**. Common practice in the past, however, has been merely to tape or clamp the filter between two sections of duct or a

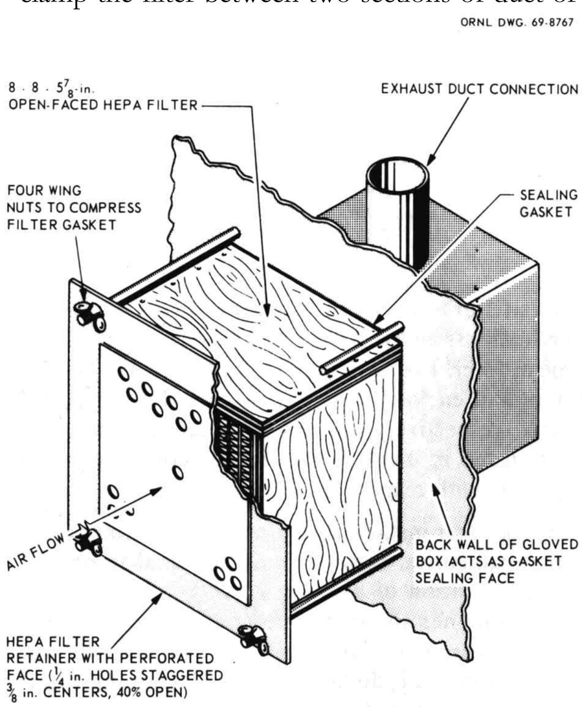

Figure 6.5 – Mounting of duct-entrance filters

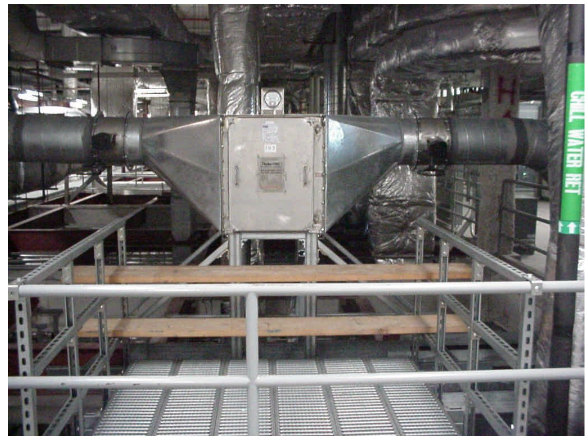

Figure 6.6 – Correct mounting of in-duct HEPA filter housing

pair of duct transitions with the case exposed. Such installations provide no secondary containment in the event of a breach of the filter case, gaskets, or tape seals, and particularly for wood-cased filters, these installations fail to meet the requirements of UL-181A[1] and NFPA 90A.[2]

6.2 HOUSINGS

Housings for in-duct installations may be as small as the side-access housings for a 25-cfm HEPA filter or as large as the complete multistage air-cleaning unit containing demister, prefilter, two stages of HEPA filters, and adsorber (**FIGURE 6.7**). Probably the most common single-component housing today is the bag-in, bag-out side-access type, which is commercially manufactured by a number of companies to a more or less standard configuration.

Commercially made side-access housings, like other air cleaning system components, are not items to be selected "on faith." Designers have been prone to look upon these as "black boxes," believing that, because they are off-the-shelf items, they can be assumed to be of adequate design and to be suitable for any nuclear application. This is not the case, and some users have been faced with replacing or upgrading many such commercial enclosures over the past several years. Features that must be checked carefully when purchasing standard commercial housings include the filter (component) mounting frame and clamping device, the rigidity of the box and its cover, the method of cover sealing and clamping, access to the installed component, the rigidity and

Figure 6.7 – Complete multi-stage air-cleaning unit

Figure 6.8 – Turned angle filter sealing surface of a commercial housing

construction of duct connections, and the materials of construction of all parts, including the component clamping mechanism. These same features are important in the design of one-of-a-kind shop-built housings.

6.2.1 COMPONENT INSTALLATION

Requirements for installing components are basically the same as those for bank installations and include structural rigidity, flatness, and accuracy of the sealing surface construction; positive, reliable sealing of the component to the frame; specification of and strict adherence to close tolerances in fabrication; and leaktight welded construction. [See Section 4.2] A minimum sheet-metal thickness of 0.078 in. (No. 14 U.S. gage) is recommended for the sealing surface of commercially made and shop-fabricated housings. For gasket-sealed housings, the sealing surface must be seal-welded into the housing in such a manner that no warping of the filter (component) sealing surface will result. There should be a right-angle bend all around the seating surface to provide reinforcement and to ensure flatness. **FIGURE 6.8** shows a portion of the turned-angle filter sealing surface of a commercial housing and **FIGURE 6.9** shows the four-bar-linkage gasket seal clamping mechanism that is operated by means of a wrench (**FIGURE 6.10**) from outside the housing. The housing should be constructed to prevent leakage through the housing where the clamping mechanism penetrates to the outside. The structural requirements of the mounting frame will be met if 14-gage steel is used, particularly if the stiffening flange (right-angle bend) is also used. Face mounting of the filter to the mounting frame is recommended, with a "finger space" of at least 2 in. on two sides, as shown in **FIGURE 6.10**, for easy access and filter replacement. Access space within the housing is particularly important in bag-in, bag-out housings. The frame fabrication and tolerance recommendations of Section 4.4.5 are applicable to both commercial and shop-built mounting frames. Flat gasket-to-knife-edge seals are not recommended because they tend to leak excessively if the knife-edge is nicked or if there is any lack of parallelism between the knife-edge and the filter face. The compression set produced by a knife-edge in only a portion of the gasket also results in leakage if there is any degree of relaxation of the clamping device. The gel seal design does not require special tolerances and have been proven to create a very effective filter-to-sealing surface method.

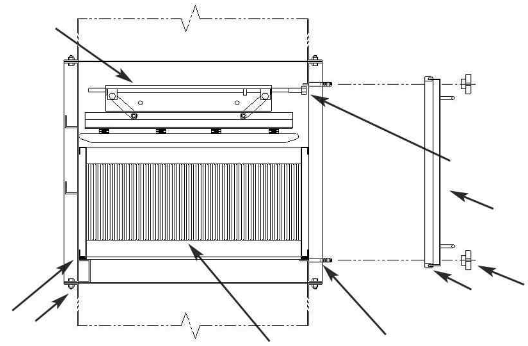

Figure 6.9 – Four-bar-linkage gasket seal clamping mechanism

Figure 6.10 – Four-bar-linkage gasket seal clamping mechanism

A nonwelded mounting frame consists of a single 0.25-in. plate sealed by gaskets between the flanges of the body and transition of a field-assembled housing. The filter is clamped by bolts and installed through a hatch in the side of the housing. As noted in Chapter 4, bolted clamping provides the maximum reliability (provided the bolts are large enough), as well as an ability to adjust to dimensional variations of the filters. As noted in Section 4.4.6, a gasket compression of at least 80 percent is needed to create a reliable seal between a high-efficiency devices such as a HEPA filter or radioiodine adsorption cell. This requires a gasket loading of something over 20 lb/in.^{2} of gasket area, or a total loading of over 1,400 lb for a 24- by 24-in. filter, or 1,050 lb for a 12- by 24-in. filter, or 700 lb for a 12- by 12-in. filter. Such loadings are easily accomplished with the bolted clamping method. It is important for the designer to verify that the clamping mechanism of the commercial housing being considered can develop the loading required and is adjustable. All parts of the mechanism should be stainless steel to prevent rusting and seizing under operational conditions. This includes springs, which tend to break when rusted. The only exception to this rule is nuts, which if used, should be brass, bronze, or another material that will not gall in contact with the stainless male-threaded part (**FIGURE 6.9**). Clamping mechanisms should be on the clean side of the filter, and operator shafts, when required, must be sealed by O-rings (see FIGURE 6.9) or glands. A rest, guides, stops, or other means for aligning the filter prior to clamping should be provided within the housing.

For gel seal housings, the knife-edge sealing surface must be seal-welded into the housing so that no warping of the filter (component) sealing surface will result. There should be a right angle all around the knife-edge sealing surface to provide reinforcement and ensure alignment. **FIGURE 6.11** shows a portion of the knife-edged filter sealing surface of a commercial housing. The gel seal housing clamping mechanism is operated by hand from the side the housing. All parts of the mechanism should be 300 series stainless steel to prevent rusting and seizing under operational conditions.

The clamping pressure required to properly seal a gasket-sealed HEPA filter or adsorber cell must be both high and uniform, as noted in Section 4.3.6. However, this requirement is substantially relaxed when gel seal systems are used. As **FIGURE 6.12** shows, the filter element has a groove filled with a non-Newtonian (i.e., nonflowing) gel. The filter is pushed against the knife-edged flange of the mounting frame so that the gel envelops the knife-edge, forming an airtight seal. Clamping pressure need only be sufficient to prevent the filter from backing away from the knife edge (which would break the seal) under any foreseeable differential pressure across the filter under either normal operating or system upset conditions. The gel, a silicone compound, has been tested and found to be capable of maintaining an adequate seal under the fire and hot air conditions of UL-586[3] and the radiation exposure requirement of ASME AG-1,

Figure 6.11 – Commercial housing filter sealing surface

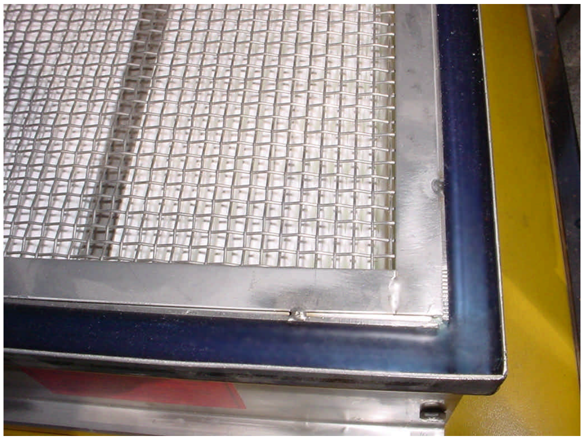

Figure 6.12 – Gel seal system

Section FC.[4]

Either the flat-gasket-to-flat-flange or the gel seal are recommended.

6.2.2 Housing Construction

The walls of the housing must be sufficiently strong to prevent "oil canning" and overstressing under an alternating positive and negative pressure equal to at least 1.5 times the maximum absolute gage pressure to which the housing will be subjected under the most severe conditions for which it is intended; a minimum design pressure of 10 in.wg is generally recommended. In general, the design and fabrication recommendations of Section 4.5.2 and the leaktightness recommendations of Section 4.3.4 are applicable to housings of these smaller dimensions. In purchasing commercial housings, the designer should check the details of construction to verify that the design proposed is, in fact, adequate for his application; that is, that the walls of the housing (or the cover) will not "oil can" and that stresses in the walls or clamping mechanism will not exceed a value of 0.7 times the yield strength of the material from which they are made under a housing pressure of 1.5 times the design pressure.

Many failures of commercial housings can be traced to corrosion. The filter housing is a common point where corrosives tend to condense, collect, and concentrate. When the filter housing is to be installed in a line that, under either normal or abnormal conditions, may contain corrosive fumes or vapors, stainless steel construction should be employed. In any event, all parts of the clamping device (including springs, but not nuts) should be stainless steel. The designer should determine which coating has to be used and should be personal satisfied that it is adequate for the application (10 to 20 years service life is often considered normal for such housings; 40 years is a figure often expressed for nuclear power reactors). Results of chemical-resistance tests, as specified in ANSI N512,[5] should be reviewed in such evaluations.

Hand knobs of the type shown in **FIGURE 6.13** should attach to the housing access door. Attachment of covers with machine bolts or nuts may be cheaper, but will be a constant problem to the user. Nuts get lost and threaded bolts get damaged under service conditions. The result is often an inability to seal the housing properly, and the need to remove and replace a large number of nuts or bolts inhibits access and proper service. For access door clamping, the door must have a 2-in. deep lip or flange all around for stiffening (**FIGURE 6.8**). The cover must also be stiff enough or sufficiently reinforced so that it will not "oil can" under the pressure variations to which it may be subjected. The cover and the cover-clamping mechanism must be capable of sealing the cover opening whether or not a bag is in place.

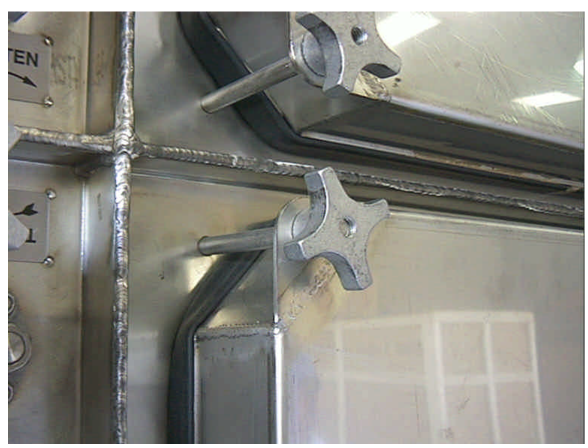

Figure 6.13 – Hand knobs

Figure 6.14 – Bag-in bag-out filter replacement

6.2.3 BAGGING

Most commercially manufactured and some one-of-a-kind shop-built housings are designed for bag-in bag-out filter replacement. **FIGURE 6.14** describe this procedure step-by-step. Shutoff dampers are needed upstream and downstream of the filter (or other component being replaced) to permit isolation of the housing during the change and ballooning or sucking in of the bag when the access door is opened due to a pressure differential between the inside and outside of the bag. A small, valved, breather vent can be specified on the clean side of the filter to control pressure in the housing; a slight negative pressure (0.25- to 0.5-in.wg) helps ensure inward leakage should the housing become pressurized due to pumping of the bag. When sealing change-out bags, two seals about 0.25-in. apart are usually made so that, when the bag is cut between them, both the housing opening and the enclosed filter are sealed from the room environment. The end users safety officer will determine the method of sealing the change-out bag that best suits the facility.

Bags must be clear plastic, typically polyvinyl chloride (PVC), to permit the worker to see what he is doing (in some Vokes and Flanders housing designs, for example, the worker must manipulate the filter clamping mechanism through the bag as **Figure 6.15** shows). Bagging materials are PVC or polyethylene, and a minimum of 0.008-in thick. Bags could be torn, particularly when used with metal-cased filters or adsorbers. Care must be taken when carrying out the procedure with larger (24- by 24- by 11.5-in.) items. Housings should be installed in a location that can be isolated as a contamination or radiation zone in the event of a bag tear and resultant spill. The excess bag material that remains after a new filter is placed into the housing is folded carefully against the side of the filter element, as shown in **FIGURE 6.14 - g**), to prevent any portion from getting into the airstream or being pinched between the housing cover and bagging ring. After folding the bag

Figure 6.15 – Use of clear bags

within the filter housing, it must be isolated from system airflow on the clean side of the filter because the plastic can be damaged from continued exposure to the airstream. The covers of bag-out housings must be capable of sealing the housing with and without the bag installed and must be kept closed when the system is in operation to protect the bag that remains in the housing. Bagging should not be considered an automatic solution to the contamination hazard, and the user is cautioned to take proper precautions during filter changes. **FIGURE 6.16** shows the possible dress for personnel engaged in a bag-out filter change when there is a possibility of high contamination levels. Note the full body cover and gas mask. Again, the end users safety officer will determine the method of filter change-out bag that best suits the facility.

Figure 6.16 – Personnel dress for bag-out filter change

6.2.4 Housing Installation

For multifilter installations, horizontal airflow with filter faces vertical is recommended for large (24- by 24-in. face dimensions) HEPA filters. This recommendation is not so important for smaller filters designed with inherently sufficient media support to resist gravitational pull on filter core and collected dust. When vertical airflow (filter face horizontal) is unavoidable, upflow is recommended to downflow because filter media sagging is offset to some extent by air pressure and because there is less chance of cross-contamination from the dirty side to the clean side of the system. With the downflow design, contaminated dust dislodged during a filter change can fall into the clean side of the system. Liquid collected in filter pleats of a downflow system will eventually seep through the media and carry dissolved contaminants into the clean side of the system. On the other hand, upflow systems may require withdrawal of contaminated filters into the clean zone. When horizontal installations must be used, filters should be designed to seal on the upper side of the mounting frame so their weight will load rather than unload on the gasket or gel-sealing surface. (**FIGURE 6.17**). Unlike

Figure 6.17 – Horizontal filter installation

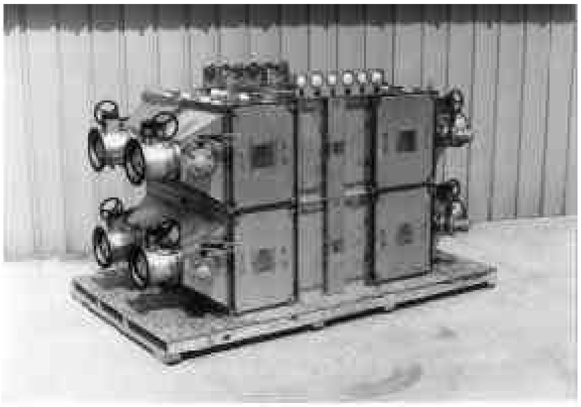

Figure 6.18 – Interconnected housings

Figure 6.19 – Flexible connections

multifilter installations, installation of the filter on the clean side (i.e., downstream) of the mounting frame is always recommended for single-filter installations

For multistage installation, components may be installed in a single housing, as seen in FIGURE 6.7, or in interconnected individual housings (**FIGURE 6.18**). Although bolted, gasketed joints are recommended, flexible connections (**FIGURES 6.19 and 6.20**) are suitable for housings connected directly to a fan. Duct-taped seals between housings and ductwork are acceptable, however, they are not recommended. Multistage installations can create problems related to periodic surveillance testing of HEPA filters and adsorber cells. Even though a flange-to-flange installation is undoubtedly the least expensive option from the standpoint of materials and space occupancy, there may be insufficient room between components to introduce a well-mixed test agent, to obtain a satisfactory upstream sample, or to probe for leaks on the downstream faces of the components. Careful planning of filter and adsorber test procedures before installation design is completed is essential, particularly for multistage installations. Although some housing specifications require and some vendors routinely furnish sample ports in the housing itself, such ports should not be automatically considered to meet the requirement for preplanned and preinstalled test ports. As noted in Chapter 8, the test agent injection port must be located well upstream of the filter or adsorber to achieve good mixing of air and agent. Upstream samples must be taken from a point in

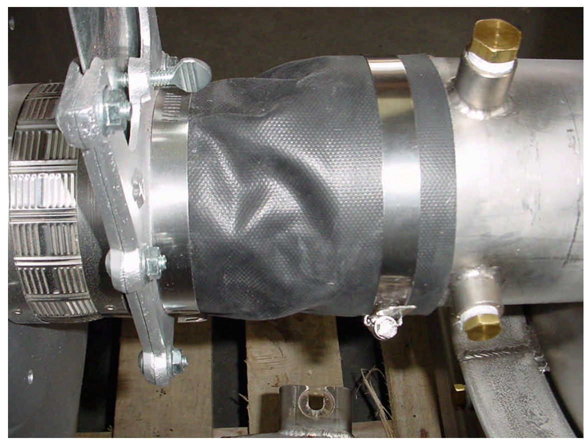

Figure 6.20 – Flexible connections

the duct that is immediately upstream of the filter or adsorber. Downstream samples must be taken at a point far enough downstream to obtain good mixing of the air and test agent that penetrates the filter or adsorber. This point is at least 10 duct diameters downstream, or preferably downstream of the fan. Fire protection is discussed in Chapter 10.

To side-step the testing problems of having ten duct diameters upstream to inject the test agent and ten duct diameters downstream to sample, in-place filter test sections are available. These test sections, as shown in **FIGURE 6.21**, allow testing without requiring the test personnel to enter the contaminated air space. They should be the same height and width of the housing that contains the filter or adsorber being tested, and the length of the test sections should be 24 to 28 in. long.

Figure 6.21 – In-place filter test section

The in-place test sections should be designed, manufactured, and tested using the same criteria as the filter housing. The test housing will use apparatus and devices that are supplied as an integral part of the test section, including mixing devices and sample ports. The upstream and downstream test chambers will contain identical mixing devices to mix and disperse a uniform challenge air/aerosol ahead of the filter and the effluent from the filter being tested. Challenge aerosol inlet ports and upstream and downstream sample ports will be provided for each HEPA filter space and will be labeled for identification.

The manufacturer of these test sections will factory-proof-test its in-place test housings by performing an air aerosol mixing uniformity test using a test housing mock-up system. This test system will contain two filter banks in series, with each bank containing at least two filters in parallel. The proof test will include upstream sample and downstream efficiency readings. The factory-proof-test will verify that a leaking filter can escape detection in the conventional ten-duct diameter test, but can be "found" by the individual efficiency test. The manufacturer will have available a detailed report for the buyer as proof that the test housing has been qualified as described.

6.3 ENCLOSED FILTER INSTALLATION

Enclosed HEPA filters often appear to offer an ideal solution to some in-duct requirements. They are by design unitary; they do not require enclosures; and, after careful removal from the duct, they can be sealed and handled without personnel coming into contact with the contaminated filter core. However, they must be used with extreme caution. These designs are not intended to replace or serve as a containment housing. First, the wood-cased type, because the case is part of the system pressure boundary, does not meet the requirements of the National Fire Codes (specifically, NFPA 90A[2]) and should not be used in any application where the potential of a filter fire exists. Second, steel-cased enclosed filters can leak and should not be used in positive-pressure applications or where the filter case could be pressurized under system-upset conditions. This design is extremely difficult to produce as a total seal welded unit. They typically are not total seal welded or meet any welding requirements. The case is part of the system pressure boundary. Neither the wood-cased or wood-cased designs complete assembly pressure boundaries are leak tested by the "Pressure Decay Method" in accordance with the requirements of ASME N510-1995.[10] Although the filter core is adequately sealed into the case to prevent leakage between case and core under normal airflow, air can leak through the joints of the case, which are simply nailed, bolted, or riveted through a layer of compressed glass-fiber matting. This seal is not airtight and under positive pressure is not an effective particle filter. For this reason, when steel-cased enclosed filters are to be used in systems in which there are or could be significant levels of contamination, it is recommended that the filters be bagged at all times.

Enclosed filters are most commonly furnished with plain nipple ends and are generally sealed into the duct by means of (1) flexible tubing and clamp rings, (2) specially designed elastomer sealing glands or cuffs, or (3) a wrap of duct tape. The third method is not reliable and, if used, the taped connection should be protected with a metal collar. All of these seals are subject to failure when exposed to fire or hot air and cannot be recommended for applications where high levels of radioactivity may be present. Flanged joints are